5/D

101 Rec'd PCT/PTO 28 NOV 1997

08/973018

A HYDRO-GENERATOR PLANT

Technical field:

The present invention relates to a hydro-generator plant of the type described in the preamble to the claim and which is intended for connection to distribution or transmission networks, hereinafter called power networks. The invention also relates to an electric generator for high voltage in a hydro-generator plant intended for the above-mentioned purpose. The invention further relates to a procedure for assembling such a plant and the manufacture of such a generator.

Background art:

The magnetic circuits in electric generators usually comprise a laminated core, e.g. of sheet steel with a welded construction. To provide ventilation and cooling the core is often divided into stacks with radial and/or axial ventilation ducts. For larger machines the laminations are punched out in segments which are attached to the frame of the machine, the laminated core being held together by pressure fingers and pressure rings. The winding of the magnetic circuit is disposed in slots in the core, the slots generally having a cross section in the shape of a rectangle or trapezium.

In multi-phase electric generators the windings are made as either single or double layer windings. With single layer windings there is only one coil side per slot, whereas with double layer windings there are two coil sides per slot. By coil side is meant one or more conductors combined vertically or horizontally and provided with a common coil insulation, i.e. an insulation designed to withstand the rated voltage of the generator to earth.

Double-layer windings are generally made as diamond windings whereas single layer windings in the present context can be made as diamond or flat windings. Only one (possibly two) coil width exists in diamond windings whereas flat windings are made as concentric windings, i.e. with widely varying coil width. By coil width is meant the distance in arc dimension between two coil sides pertaining to the same coil.

Normally all large machines are made with double-layer winding and coils of the same size. Each coil is placed with one side in one layer and the other side in the other layer. This means that all coils cross each other in the coil end. If there are more than two

layers these crossings complicate the winding work and the coil end is less satisfactory.

It is considered that coils for rotating generators can be manufactured with good results within a voltage range of 3 - 20 kV.

It is also generally known that connection of a synchronous machine to a power network must be via a Δ/Y-connected or step-up transformer, since the voltage of the power network is generally higher than the voltage it has hitherto been able to achieve with the electric machine. Thus this transformer and the synchronous machine constitute integrated parts of a plant. The transformer entails an extra cost and also has the drawback that the total efficiency of the system is reduced. If, therefore, it were possible to manufacture electric generators for considerably higher voltages, the step-up transformer could be eliminated.

Although the dominant known technology for supplying current from a generator to a high-voltage network, a concept which in the present application applies to the level of 20 kV and upwards, preferably higher than 36 kV, is for a transformer to be inserted between the generator and the power network, it is already known to attempt to eliminate the transformer and generate the high voltage directly out to the power network at its voltage level. Such generators are described, for instance, in US-A-4 429 244, US-A-4 164 672 and US-A-3 743 867.

However, the machine designs according to the above publications do not permit optimal utilization of the electromagnetic material in the stator.

Description of the invention:

The object of the invention is thus to provide an electric generator which can be used in a hydro-generator plant for such high voltage that the above-mentioned Δ/Y-connected step-up transformer can be omitted, i.e. a plant in which the electric generators are intended for considerably high voltages than conventional machines of corresponding type, in order to be able to execute direct connection to power networks at all types of high voltage.

This object has been achieved according to the invention in that a plant of the type described in the preamble to claim 1 is given the special features defined in the characterizing part of this claim, in that a generator of the type described in the preamble to claim 34 is given the special features defined in the characterizing part

of this claim, and in that a procedure of the type described in the preamble to claims 33 and 36 includes the special measures defined in the characterizing parts of respective claims.

Thanks to the solid insulation in combination with the other features defined, the network can be supplied without the use of an intermediate step-up transformer even at network voltages considerably in excess of 36 kV.

The fact that the solid insulation enables the windings to be arranged for direct connection to the high-voltage network, thus eliminating the step-up transformer, offers great advantages over known technology.

The elimination of the transformer per se entails great savings, for instance, and the absence of the transformer also results in several other simplifications and thus savings.

A plant of this type is often arranged in a rock chamber where, with conventional technology, the transformer is arranged either in direct connection with the generator in the rock chamber or above ground at a distance of several hundred metres and connected to the generator by a busbar system. Compared with the first alternative, elimination of the transformer enables the volume of the rock chamber to be greatly reduced. The fire risk entailed with an oil-insulated transformer is also eliminated therefore reducing the necessity for extensive fire-safety precautions such as special evacuation routes for personnel.

In the alternative in which the transformer is placed above ground the busbar system is more extended due to the longer distance between the generator and the transformer. Since the current in the busbars (normally with aluminium conductors) is considerable, in the order of 10-20 kA, the power losses are large. Moreover, busbar systems introduce a risk for 2- and 3-phase faults during which the currents are considerable.

With the present invention two major objectives are achieved:
- The losses in the busrun are reduced due to the high voltage.
- The risk for 2- and 3-phase failures is considerably reduced due to the use of insulated HV cables.

The reduction in the number of electrical components achieved with the invention therefore means that the corresponding safety equipment can be omitted.

Furthermore, the rock chamber need not be blasted to allow laying of the busbar system, which entails a saving in rock chamber space of several thousand cubic metres.

The plant according to the invention also enables several connections with different voltage levels to be arranged, i.e. the invention can be used for all auxiliary power in the power station.

In all, the advantages mentioned above entail radically improved total economy for the plant. The plant cost, typically in the order of some hundred million SEK, is reduced by 30-50 %. Operating economy is improved both by less need for maintenance and by an increase in the degree of efficiency by 1-1.5 %. For an operating time of 8000 h/year, an output level corresponding to 150 MVA, a kWh price of SEK 0.20 and a useful service life of 30 years the gain would be approximately SEK 75 - 100 million per generator.

In a particularly preferred embodiment of the plant and generator respectively, the solid insulation system comprises at least two layers, each layer constituting essentially an equipotential surface, and also intermediate solid insulation therebetween, at least one of the layers having substantially the same coefficient of thermal expansion as the solid insulation.

This embodiment constitutes an expedient embodiment of the solid insulation that in an optimal manner enables the windings to be directly connected to the high-voltage network and where harmonization of the coefficients of thermal expansion eliminates the risk of defects, cracks or the like upon thermal movement in the winding.

It should be evident that the windings and the insulating layers are flexible so that they can be bent.

It should also be pointed out that the plant according to the invention can be constructed using either horizontal or vertical generators, which may be of either underground or aboveground type.

The above and other preferred embodiments of the invention are defined in the dependent claims.

The major and essential difference between known technology and the embodiment according to the invention is thus that this is achieved with a magnetic circuit included in an electric generator which is arranged to be directly connected via only breakers and isolators to a high supply voltage in the vicinity of between 20 and 800 kV, preferably higher than 36 kV. The magnetic circuit thus comprises

a laminated core having at least one winding consisting of a threaded cable with one or more permanently insulated conductors having a semiconducting layer both at the conductor and outside the insulation, the outer semiconducting layer being connected to earth potential.

To solve the problems arising with direct connection of electric machines to all types of high-voltage power networks, the generator in the plant according to the invention has a number of features as mentioned above, which differ distinctly from known technology. Additional features and further embodiments are defined in the dependent claims and are discussed in the following.

Such features mentioned above and other essential characteristics of the generator and thus of the hydro-generator plant according to the invention include the following:

- The winding of the magnetic circuit is produced from a cable having one or more permanently insulated conductors with a semiconducting layer at both conductor and sheath. Some typical conductors of this type are PEX cable or a cable with EP rubber insulation which, however, for the present purpose are further developed both as regards the strands in the conductor and the nature of the outer sheath.

- Cables with circular cross section are preferred, but cables with some other cross section may be used in order to obtain better packing density, for instance.

- Such a cable allows the laminated core to be designed according to the invention in a new and optimal way as regards slots and teeth.

- The winding is preferably manufactured with insulation in steps for best utilization of the laminated core.

- The winding is preferably manufactured as a multi-layered, concentric cable winding, thus enabling the number of coil-end intersections to be reduced.

- The slot design is suited to the cross section of the winding cable so that the slots are in the form of a number of cylindrical openings running axially and/or radially outside each other and having an open waist running between the layers of the stator winding.

- The design of the slots is adjusted to the relevant cable cross section and to the stepped insulation of the winding. The

stepped insulation allows the magnetic core to have substantially constant tooth width, irrespective of the radial extension.

- The above-mentioned further development as regards the strands entails the winding conductors consisting of a number of impacted strata/layers, i.e. insulated strands that from the point of view of an electric machine, are not necessarily correctly transposed, uninsulated and/or insulated from each other.

- The above-mentioned further development as regards the outer sheath entails that at suitable points along the length of the conductor, the outer sheath is cut off, each cut partial length being connected directly to earth potential.

The use of a cable of the type described above allows the entire length of the outer sheath of the winding, as well as other parts of the plant, to be kept at earth potential. An important advantage is that the electric field is close to zero within the coil-end region outside the outer semiconducting layer. With earth potential on the outer sheath the electric field need not be controlled. This means that no field concentrations will occur either in the core, in the coil-end regions or in the transition between them.

The mixture of insulated and/or uninsulated impacted strands, or transposed strands, results in low stray losses.

The cable for high voltage used in the magnetic circuit winding is constructed of an inner core/conductor with a plurality of strands, at least two semiconducting layers, the innermost being surrounded by an insulating layer, which is in turn surrounded by an outer semiconducting layer having an outer diameter in the order of 20-200 mm and a conductor area in the order of 40-3000 mm^2.

The solid insulation in a generator according to the invention also offers great advantages when constructing a hydro-generator plant. The absence of wet insulation means that the stator of the generator need not be completed at the factory but can instead be delivered in parts and assembled on site. A stator of the size under consideration here is large and heavy which has entailed transport problems with conventional designs where the roads must be reinforced and dimensioned for the vast weight. This problem is eliminated since the stator for a generator can be delivered in parts.

The invention thus also relates to the procedures as defined in claims 30 and 33, where this possibility is exploited when building

a hydro-generator plant and manufacturing a generator, respectively.

Brief description of the drawings:

The invention will be described in more detail in the following detailed description of a preferred embodiment of constructing the magnetic circuit of the electric generator in the hydro-generator plant, with reference to the accompanying drawings in which

Figure 1 shows a schematic axial end view of a sector of the stator in an electric generator in the hydro-generator plant according to the invention,

Figure 2 shows an end view, partially stripped, of a cable used in the winding of the stator according to Figure 1,

Figure 3 shows a simplified view, partially in section, of a hydro-generator arrangement according to the invention,

Figure 4 shows a circuit diagram for the hydro-generator plant according to the invention,

Figure 5 shows a section through a conventional hydro-generator plant.

Figure 6 is a diagram showing a traditional solution for auxiliary power for a hydro plant, and

Figure 7 is a diagram showing generators with build-in windings for generation of auxiliary power according to the invention.

Description of a preferred embodiment:

In order to understand certain aspects of the advantages of the invention, reference is made initially to Figure 5 showing an example of a conventional hydro-generator plant. This is of a type with the transformer hall 501 situated some way from the generator hall 502, the latter being in the form of a rock chamber housing the generator 503. The generator 503 is connected to the transformer in the transformer hall 501 via a busbar system 505 arranged in a tunnel system 504 several hundred metres long. A plant according to the invention entirely eliminates the part to the right of the line A-A in Figure 5, while substantially the same dimensions are retained in the generator hall 502. A conventional plant without the transformer situated above ground as shown in Figure 5 would instead require a considerably larger generator hall

502 to allow space for the transformer and its auxiliary and safety equipment.

The rotor 2 of the generator is also indicated in the schematic axial view through a sector of the stator 1 according to Figure 1, pertaining to the generator 100 (Figure 3) included in the hydro-generator plant. The stator 1 is composed in conventional manner of a laminated core. Figure 1 shows a sector of the generator corresponding to one pole pitch. From a yoke part 3 of the core situated radially outermost, a number of teeth 4 extend radially in towards the rotor 2 and are separated by slots 5 in which the stator winding is arranged. Cables 6 forming this stator winding, are high-voltage cables which may be of substantially the same type as those used for power distribution, i.e. PEX cables. PEX = crosslinked polyethylene (XLPE). One difference is that the outer, mechanically-protective sheath, and the metal screen normally surrounding such power distribution cables are eliminated so that the cable for the present application comprises only the conductor and at least one semiconducting layer on each side of an insulating layer. Thus, the semiconducting layer which is sensitive to mechanical damage lies naked on the surface of the cable.

The cables 6 are illustrated schematically in Figure 1, only the conducting central part of each cable part or coil side being drawn in. As can be seen, each slot 5 has varying cross section with alternating wide parts 7 and narrow parts 8. The wide parts 7 are substantially circular and surround the cabling, the waist parts between these forming narrow parts 8. The waist parts serve to radially fix the position of each cable. The cross section of the slot 5 also narrows radially inwards. This is because the voltage on the cable parts is lower the closer to the radially inner part of the stator 1 they are situated. Slimmer cabling can therefore be used there, whereas coarser cabling is necessary further out. In the example illustrated cables of three different dimensions are used, arranged in three correspondingly dimensioned sections 51, 52, 53 of slots 5. An auxiliary power winding 9 is arranged furthest out in the slot 5.

Figure 2 shows a step-wise stripped end view of a high-voltage cable for use in an electric machine according to the present invention. The high-voltage cable 6 comprises one or more conductors 31, each of which comprises a number of strands 36 which together give a circular cross section of copper (Cu), for instance. These conductors 31 are arranged in the middle of the high-voltage cable 6 and in the shown embodiment each is surrounded

by a part insulation 35. However, it is feasible for the part insulation 35 to be omitted on one of the conductors 31. In the present embodiment of the invention the conductors 31 are together surrounded by a first semiconducting layer 32. Around this first semiconducting layer 32 is an insulating layer 33, e.g. PEX insulation, which is in turn surrounded by a second semiconducting layer 34. Thus the concept "high-voltage cable" in this application need not include any metallic screen or outer sheath of the type that normal surrounds such a cable for power distribution.

A hydro-generator with a magnetic circuit of the type described above is shown in Figure 3 where the generator 100 is driven by a water turbine 102 via a common shaft 101.

The stator 1 of the generator 100 thus carries the stator windings 10 which are built up of the cable 6 described above. The cable 6 is unscreened and changes to a screened cable 11 at the cable splicing 9.

With a hydro-generator 100 according to the invention it is thus possible to generate extremely high electric voltages of up to approximately 800 kV. It is thus possible to electrically connect the hydro-generator 100 directly to a distribution or transmission network 110 with an intermediate step-up transformer or similar electric machine as is generally the case in conventional plants where equivalent generators are able at most to generate voltages of up of 25-30 kV.

Figure 4 illustrates a hydro-generator plant according to the present invention. In conventional manner, the generator 100 has an excitation winding 112 and one (or more) auxiliary power winding(s) 113. In the shown embodiment of the plant according to the invention the generator 100 is earthed via an impedance 103.

It can also be seen from Figure 4 that the generator 100 is electrically connected via the cable splicing 9 to the screened cable 11 (see also Figure 3). The cable 11 is provided with current transformers 104 in conventional manner, and terminates at 105. After this point 105 the electric plant in the shown embodiment continues with busbars 106 having branches with voltage transformers 107 and surge arresters 108. However, the main electric supply takes place via the busbars 106 directly to the distribution or transmission network 110 via isolator 109 and circuit-breaker 111.

A hydro-generator plant according to the invention is designed for operation either to generate electric voltage for the power network

as described above, or as a pump plant, i.e. to be driven from the electric power network 110. The generator 100 then operates as a motor to drive the turbine 102 as a pump.

Thus, with the hydro-generator 100, no intermediate coupling of a step-up transformer is required. With the hydro-generator plant according to the present invention, therefore, several transformer and breaker units previously necessary are eliminated, which is obviously an advantage - not least from the aspects of cost and operating reliability.

Although the hydro-generator and the plant in which this generator is included have been described and illustrated in connection with an embodiment by way of example, it should be obvious to one skilled in that art that several modifications are possible without departing from the inventive concept. The generator may be earthed directly, for instance, without any impedance. The auxiliary windings can be omitted, as also other components shown. Although the invention has been exemplified with a three-phase plant, the number of phases may be more or less.